METHOD FOR USING POTASSIUM CHANNEL AGONISTS FOR DELIVERING A MEDICANT TO AN ABNORMAL BRAIN REGION AND/OR A MALIGNANT TUMOR

BACKGROUND OF THE INVENTION

Throughout the application various publications are referenced in parentheses. The
.5   disclosures of these publications in their entireties are hereby incorporated by reference in the
application in order to more fully describe the state of the art to which this invention pertains.

1. THE FIELD OF THE INVENTION

This invention relates to the medical arts. In particular, it relates to a method of
enhancing the delivery of a medicant across abnormal microvasculature to a tissue requiring
10   treatment.

2. DISCUSSION OF THE RELATED ART

Pathologic neovascularization, i.e., the proliferation or development of new blood
vessels, is essential for the growth and spread of primary, secondary and metastatic malignant
tumors. It is known that certain properties of the new capillaries and arterioles constituting the
15   neomicrovasculature in solid tumors differ from those of normal microvasculature. (J.
Denekamp *et al.*, *Vasculature and microenvironmental gradients: the missing links in novel
approaches to cancer therapy?*, Adv. Enzyme Regul. 38:281-99 [1998]). Neomicrovasculature
induced by angiogenic factors from malignant cells was reported to possess altered
pharmacological reactivity to some vasoconstricting agents, compared with neomicrovasculature
20   that was not induced by neoplastic cells. (S.P. Andrade and W.T. Beraldo, *Pharmacological
reactivity of neoplastic and non-neoplastic associated neovasculature to vasoconstrictors*, Int.
J. Exp. Pathol. 79(6):425-32 [1998]).

A number of proposed cancer treatments have been based on differences between
neomicrovasculature and normal microvasculature. For example, combretastatin A-4 was shown
25   to cause vascular damage and occlusion selectively in the blood vessels of malignant tumors
compared to normal blood vessels. (G.G. Dark *et al.*, *Combretastatin A-4, an agent that displays*

potent and selective toxicity toward tumor vasculature, Cancer Res. 57(10):1829-34 [1997]; D.J. Chaplin *et al.*, *Anti-vascular approaches to solid tumour therapy: evaluation of combretastatin A4 phosphate*, Anticancer Res. 19(1A):189-95 [1999]).   Monoclonal antibodies have been directed to antigens and antigenic combinations specific to endothelial cells of pathologic

5   neovasculature, such as vascular cell adhesion molecule (VCAM)-1, phosphatidylserine (PS), the glycoprotein endosialin, and prostate-specific membrane antigen (PSMA), with the aim of selectively inducing thrombosis in neovasculature.   (E.g., S. Ran *et al.*, *Infarction of solid Hodgkin's tumors in mice by antibody-directed targeting of tissue factor to tumor vasculature*, Cancer Res. 58(20):4646-53 [1998]; I. Ohizumi *et al.*, *Antibody-based therapy targeting tumor*

10   *vascular endothelial cells suppresses solid tumor growth in rats*, Biochem. Biophys. Res. Commun. 236(2):493-96 [1997]; S.S. Chang *et al.*, *Five different antiprostate-specific membrane antigen (PSMA) antibodies confirm PSMA expression in tumor-associated neovasculature*, Cancer Res. 59(13):3192-98 [1999]; W.J. Rettig *et al.*, *Identification of endosialin, a cell surface glycoprotein of vascular endothelial cells in human cancer*, Proc. Natl.

15   Acad. Sci. USA 89(22):10832-36 [1992]).   But taken alone, shutting down blood flow through the neomicrovasculature to malignant tumors may not necessarily result in stopping tumor growth, because actively proliferating populations of neoplastic cells at the periphery of solid tumors may have access to blood supplied by normal microvasculature. (E.g., D.J. Chaplin *et al.* [1999]).

20   Consequently, other conventional and novel therapeutic modalities will continue to be of value in the treatment of malignant, solid tumors. However, the efficacy of novel therapeutic agents, including cytotoxic chemotherapeutic agents, monoclonal antibodies, cytokines, effector cells, and viral particles has been limited by their ability to reach their targets in vivo in adequate quantities. (E.g., R.K Jain, *Vascular and interstitial barriers to delivery of therapeutic agents*

25   *in tumors*, Cancer Metastasis Rev. 9(3):253-66 [1990]). An important limiting factor is the low permeability to macromolecules and viral particles of neomicrovasculature supplying the tumors.

This problem of microvascular permeability is especially acute with respect to malignant tumors of the central nervous system.   These malignancies are usually fatal, despite recent advances in the areas of neurosurgical techniques, chemotherapy and radiotherapy. In particular,

there are no standard therapeutic modalities that can substantially alter the prognosis for patients

with malignant tumors of the brain, cranium, and spinal cord. For example, high mortality rates

persist for patients diagnosed with malignant medulloblastomas, malignant meningiomas,

malignant neurofibrosarcomas and malignant gliomas, which are characterized by infiltrative

5   tumor cells throughout the brain.   Although intracranial tumor masses can be debulked

surgically, treated with palliative radiation therapy and chemotherapy, the survival associated

with intracranial tumors, for example, a glioblastoma, is typically measured in months. The

development of new therapeutic modalities against solid brain tumors largely depends on

transvascular delivery of the potential therapeutic agent.

10   Transvascular delivery of chemotherapeutic agents and viral particles to tumor cells or

other abnormal brain tissue is hampered by the blood-brain barrier, particularly the blood-tumor

barrier found in brain tumors. The blood-brain barrier is a transvascular permeability barrier

thought to result from the interendothelial tight junctions formed by the cerebrovascular

endothelial cells of brain capillaries and arterioles in both normal and abnormal brain tissue. The

15   blood-brain barrier protects the brain from changes in the composition of the systemic blood

supply (e.g., in electrolytes) or from blood-borne macromolecules, such as immunoglobulins or

other polypeptides, and prevents the transvascular delivery of many exogenously supplied

pharmaceutical agents to brain tissues.

The treatment of brain tissue abnormalities, such as tumors, often involves the use of

20   pharmaceutical agents with a significant toxicity of their own, making it highly desirable to be

able to preferentially direct such agents to the abnormal or malignant tissue.   While, there has

been a great deal of interest in developing techniques which are capable of opening the blood-

brain barrier to allow transport of pharmaceutical agents to the brain. Few of these methods are

capable of selectively opening the blood-brain barrier only in the abnormal brain tissue while

25   leaving the blood-brain barrier in the normal brain tissue intact.

For example, Neuwelt *et al.* used an intracarotid injection of hypertonic mannitol to

osmotically disrupt the blood-brain barrier. They reported that this enhanced the uptake by brain

tissue of inactivated HSV-1 particles that were administered immediately afterward by

intracarotid bolus injection.   (E.A. Neuwelt *et al.*, *Delivery of ultraviolet-inactivated 35S-*

herpesvirus across an osmotically modified blood-brain barrier, J. Neurosurg. 74(3):475-79 [1991]; Also, S.E. Doran *et al., Gene expression from recombinant viral vectors in the central nervous system after blood-brain barrier disruption*, Neurosurgery 36(5):965-70 [1995]; G. Nilaver *et al., Delivery of herpesvirus and adenovirus to nude rat intracerebral tumors after*

5   *osmotic blood-brain barrier disruption*, Proc. Natl. Acad. Sci. USA 92(21):9829-33 [1995]).

Intracarotid infusion of leukotriene C.sub.4 (LTC.sub.4) selectively increases the permeability in brain tumor capillaries without affecting the permeability in normal brain capillaries. The effect of LTC.sub.4 on brain tumor capillaries is, however, limited to small molecules and it can only slightly increase the permeability of those small molecules in abnormal

10 brain tissue relative to normal. Accordingly, LTC.sub.4 does not significantly increase the delivery of some larger water soluble molecules to brain tumors or other abnormalities.

The vasoactive nanopeptide bradykinin and agonists or polypeptide analogs thereof (e.g., receptor-mediated permeabilizers [RMPs]) have been injected intravenously to increase blood-brain barrier permeability to co-administered neuropharmaceutical or diagnostic agents. (B.

15 Malfroy-Camine, *Method for increasing blood-brain barrier permeability by administering a bradykinin agonist of blood-brain barrier permeability*, U.S. Patent No. 5,112,596; J.W. Kozarich *et al., Increasing blood brain barrier permeability with permeabilizer peptides*, U.S. Patent No. 5,268,164). Intracarotid infusion of bradykinin will selectively increase permeability 2- to 12-fold in brain tumor and ischemic brain capillaries for molecules ranging in molecular

20 weight from 100 to 70,000 Daltons (Inamura, T. *et a l.*, Bradykinin selectively opens blood-tumor barrier in experimental brain tumors, J. Cereb. Blood Flow Metab. 14(5):862-70 [1994]). Bradykinin does not increase permeability in the normal blood brain barrier except at very high doses. (Wirth, K. *et al., DesArg9-D-Arg[Hyp3,Thi5,D-Tic7,Oic8]bradykinin (desArg10-[Hoe140]) is a potent bradykinin B1 receptor antagonist*, Eur. J. Pharmacol.

25 205(2):217-18 [1991]). Opening of the blood-tumor barrier by bradykinin is transient, lasting 15 to 20 minutes. (Inamura *et al.* [1994]). After opening of abnormal brain capillaries with bradykinin, the capillaries become refractory to the bradykinin effect for up to 60 minutes. (Inamura *et al.* [1994]).

A method for selectively delivering to abnormal brain tissue a neuropharmaceutical agent (e.g., 5-fluorouracil, cisplatin, methotrexate, or monoclonal antibodies) or a diagnostic agent (e.g., technicium-99 glucoheptonate, gallium-EDTA, and ferrous magnetic or iodinated contrasting agents) employed intracarotid infusion of bradykinin, or a bradykinin analog, such

5   as RMP-7; the bradykinin or bradykinin analog was administered approximately contemporaneously with the agent. (K.L. Black, *Method for selective opening of abnormal brain tissue capillaries*, U.S. Patent Nos. 5,527,778 and 5,434,137). Enhanced transvascular delivery of HSV-derived viral particles to malignant cells in the brains of rats was also achieved by disrupting the blood-brain barrier with bradykinin or RMP-7. (N.G. Rainov, *Selective uptake*

10   *of viral and monocrystalline particles delivered intra-arterially to experimental brain neoplasms*, Hum. Gene. Ther. 6(12):1543-52 [1995]; N.G. Rainov *et al.*, *Long-term survival in a rodent brain tumor model by bradykinin-enhanced intra-arterial delivery of a therapeutic herpes simplex virus vector*, Cancer Gene Ther. 5(3):158-62 [1998]; F.H. Barnett *et al.*, *Selective delivery of herpes virus vectors to experimental brain tumors using RMP-7*, Cancer Gene Ther.

15   6(1):14-20 [1999]).

The calcium-activated potassium channel (K_{Ca}) is an important regulator of cerebral blood vessel tone (Nelson MT, Quayle JM. *Physiological roles and properties of potassium channels in arterial smooth muscle*, Am. J. Physiol. 268(4 Pt 1): C799-822[1995]). The K_{Ca} channel is ubiquitously distributed in tissues as α and β subunits. Its activity is triggered by

20   depolarization and enhanced by an increase in cytosolic calcium di-cation (Ca^{2+}). A local increase in Ca^{2+} is sensed by the extremely sensitive brain α-subunit of the K_{Ca}, directed towards the cytoplasm in the cell, that allows a significant potassium cation flux through these channels.

Under conditions when intracellular cyclic 3', 5' adenosine monophosphate (cAMP) concentration rises in vascular endothelium (e.g. hypoxia), ATP-sensitive potassium channels

25   (K_{ATP}) may also play a role. (J.E. Brian *et al.*, *Recent insights into the regulation of cerebral circulation*, Clin. Exp. Pharmacol. Physiol. 23(6-7):449-57 [1996]). Minoxidil sulfate and chromakalim are reported to be activators of K_{ATP}. (A.D. Wickenden *et al.*, *Comparison of the effects of the K(+)-channel openers cromakalim and minoxidil sulphate on vascular smooth muscle*, Br. J. Pharmacol, 103(1):1148-52 [1991]).

Treatments directed to the use of potassium channel activators or agonists have been taught for disorders including hypertension, cardiac and cerebral ischemia, nicotine addiction, bronchial constriction, and neurodegenerative diseases, but not particularly for the treatment of malignant tumors. (Erhardt et al., *Potassium channel activators/openers*, U.S. Patent No.

5   5,416,097; Schohe-Loop et al., *4, 4'-bridged bis-2, 4-diaminoquinazolines*, U.S. Patent No. 5,760,230; Sit et al., *4-aryl-3-hydroxyquinolin-2-one derivatives as ion channel modulators*, U.S. Patent No. 5,922,735;Garcia et al., *Biologically active compounds*, U.S. Patent No. 5,399,587; Cherksey, *Potassium channel activating compounds and methods of use thereof*, U.S. Patent No. 5,234,947).

10   Bradykinin is thought to increase $[Ca^{2+}]_i$ and thus may activate K_{Ca} channels. While some other known activators of K_{Ca} do not act as vasodilators, for example, 1,3-dihydro-1-[2-hydroxy-5-(trifluoromethyl)phenyl]-5-(trifluoromethyl)-2H-benzimidazol-2-one (NS-1619; M. Holland et al., *Effects of the BKCa channel activator, NS1619, on rat cerebral artery smooth muscle*, Br J Pharmacol, 117(1):119-29 [1996]), evidence is accumulating that K_{Ca} may play an important

15   role in vasodilatation mediated by vasodilators, such as bradykinin, NO-donors, cGMP, and guanylate cyclase activators. (Berg T., Koteng O., *Signaling pathways in bradykinin- and nitric oxide-induced hypotension in the normotensive rat; role of K+-channels*, Br. J. Pharmacol.;121(6):1113-20 [1997]; Bolotina, V.M. et al., *Nitric oxide directly activates calcium-dependent potassium channels in vascular smooth muscle*, Nature 368(6474):850-3

20   [1994]; Robertson, B.E., et al., *cGMP-dependent protein kinase activates Ca-activated K channels in cerebral artery smooth muscle cells*, Am. J. Physiol. 265(1 Pt 1):C299-303 [1993]; Sobey, C.G. et al., *Mechanisms of bradykinin-induced cerebral vasodilatation in rats. Evidence that reactive oxygen species activate K+ channels*, Stroke 28(11):2290-4; discussion 2295 [1997]; C.G. Sobey and F.M. Faraci, *Effect of nitric oxide and potassium channel agonists*

25   *and inhibitors on basilar artery diameter*, Am. J. Physiol. 272(1 Pt 2):H256-62 [1997]).

Bradykinin's action as a powerful vasodilator is disadvantageous when using bradykinin to open the blood-brain barrier to therapeutic anticancer agents. Bradykinin or its analogs may adversely lower blood pressure, reduce cerebral blood flow, or contribute to brain edema in some patients. (E.g., A.M. Butt, *Effect of inflammatory agents on electrical resistance across the*

blood-brain barrier in pial microvessels of anesthetized rats, Brain Res. 696(1-2):145-50 [1995]). In addition, bradykinin constricts smooth muscle and stimulates pain receptors.

Consequently, there is still a definite need to maximize the effectiveness of a wide variety of therapeutic agents through enhanced selective transvascular delivery to malignant

5   tumors, including those of the central nervous system, and/or to other abnormal brain regions. These and other benefits the present invention, employing potassium channel agonists, provides as described herein.

SUMMARY OF THE INVENTION

The present invention relates to a method of delivering a medicant to an abnormal brain

10   region in a mammalian subject, including a human. The method includes administering to the subject a potassium channel agonist other than bradykinin or a bradykinin analog, for example NS-1619 or minoxidil, under conditions and in an amount sufficient to increase the permeability to the medicant of a capillary or arteriole delivering blood to cells of the abnormal brain region in the subject. Simultaneously or substantially simultaneously with the potassium channel

15   agonist, the medicant is administered, so that the medicant is delivered selectively to the cells of the abnormal region compared to normal brain regions, due to the increased permeability of capillaries and arterioles supplying the abnormal brain region. The method is particularly valuable in the treatment of physical or biochemical brain injuries caused by trauma, infection, stroke, ischemia, and, particularly, malignant brain tumors, for which survival rates are

20   notoriously poor.

The present invention also relates to a method of delivering a medicant to a malignant tumor in the brain or anywhere in the body of a mammalian subject. The method involves administering to the subject a potassium channel agonist, other than bradykinin or a bradykinin analog, under conditions and in an amount sufficient to increase the permeability to the medicant

25   of a capillary or arteriole delivering blood to cells of the malignant tumor in the subject. Simultaneously or substantially simultaneously with the potassium channel agonist the medicant is administered to the subject, and it is delivered selectively to the malignant cells compared to non-malignant cells by virtue of the potassium channel agonist. The inventive method is useful

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in treating any kind of malignant tumor by increasing the selectivity of drug delivery to neoplastic tissue, thereby minimizing damage to non-malignant tissue from medicants, including cytotoxic chemotherapeutic agents, and focusing the therapeutic or diagnostic action of the agents. Thus, this invention, also directed to a method of treating a malignant tumor in a human

5   subject, offers enhanced prospects of survival to cancer patients, with fewer harmful side effects.

The selectivity of the methods is based on the role of calcium- and ATP-dependent potassium transporters (channels) in mediating the permeability of microvasculature to various drugs, macromolecules, and viral particles, combined with the greater number of calcium- and ATP-dependent potassium channels present in abnormal brain vasculature or tumor

10   neomicrovasculature compared to normal microvasculature.

The present invention also relates to a pharmaceutical composition that comprises a combination of a potassium channel agonist, other than bradykinin or a bradykinin analog, formulated in a pharmaceutically acceptable solution together with a medicant for delivery by intravascular infusion or bolus injection into a mammal, such as a human. The pharmaceutical

15   composition is useful in practicing the inventive methods.

The invention also relates to a kit for enhancing the delivery of a medicant to an abnormal brain region and/or to a malignant tumor.

These and other advantages and features of the present invention will be described more fully in a detailed description of the preferred embodiments which follows.

20   BRIEF DESCRIPTION OF THE DRAWINGS

The file of this patent contains at least one drawing executed in color. Copies of this patent with color drawing(s) will be provided by the Patent and Trademark Office upon request and payment of the necessary fee.

Figure 1A shows the enhancing effect of NS-1619 on blood-tumor barrier

25   permeability to [^{14}C]α-aminoisobutyric acid (AIB) tracer (left) compared to the effect on blood-brain barrier permeability in normal brain tissue adjacent (middle) and contralateral (right) to malignant RG2 glioma tissue in Wistar rats.

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Figure 1B shows the enhancing effect of minoxidil sulfate on blood-tumor barrier permeability to [^{14}C]AIB tracer (left) compared to the effect on blood-brain barrier permeability in normal brain tissue adjacent (middle) and contralateral (right) to malignant RG2 glioma tissue in Wistar rats.

Figure 2 shows a dose-response to NS-1619 in the unidirectional transfer constant K_i for [^{14}C]α-aminoisobutyric acid in malignant RG2 glioma tissue in Wistar rats. $K_i = \mu L/g/min$.

Figure 3 shows specific inhibition by iberiotoxin (IBTX; 2.3 µg kg^{-1} min^{-1}) of the permeability increasing effect of NS-1619 (26.5 µg kg^{-1} min^{-1}). The K_i was determined in RG2 tumor-bearing Wistar rats using [^{14}C]AIB with NS-1619 (26.5 µg kg^{-1} min^{-1}) with or without IBTX (2.3 µg kg^{-1} min^{-1}), for 15 minutes. The results are compared with PBS, pH 7.4 with or without 5% ethanol.

Figure 4 shows intense over-expression of K_{Ca} as indicated by anti-K_{Ca} immunostain of glioma tissue (Fig. 4B), compared to normal contralateral brain tissue (Fig. 4A). Magnification is 100x.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The inventive methods are useful for selectively delivering a medicant to abnormal brain regions and/or malignant tumors in mammalian subjects. The methods involve administering to the mammalian subject a potassium channel agonist, other than bradykinin or a bradykinin analog, under conditions and in an amount sufficient to increase the permeability to the medicant of a capillary or arteriole delivering blood to cells of the abnormal brain region and/or to malignant cells of a malignant tumor present in the subject. The increase in permeability ranges from at least 2-to 6-fold, compared to controls without the administration of a potassium channel agonist. The relative increase in permeability tends to be greater for large molecular weight medicants (e.g., about 10,000 to 250,000 D) than for smaller molecular weight substances (e.g., about 50-200 D).

The abnormal brain regions include regions of brain tissue physiologically directly affected by a physical or biochemical injury, for example, Alzheimer's disease, Parkinsonism,

trauma, infection, stroke, brain ischemia, or regions of neoplastic growth within the brain, such as benign or malignant brain tumor tissues.

The present invention is also useful for selectively delivering a medicant to a malignant tumor in the brain or to a tumor elsewhere in the body of a mammalian subject. The inventive

5 technology is useful in the treatment of all kinds of solid malignant tumors, including gliomas, glioblastomas, oligodendrogliomas, astrocytomas, ependymomas, primitive neuroectodermal tumors, atypical meningiomas, malignant meningiomas, neuroblastomas, sarcomas, melanomas, lymphomas, or carcinomas. The tumor to be treated can be contained in the skull, brain, spine, thorax, lung, peritoneum, prostate, ovary, uterus, breast, stomach, liver, bowel, colon, rectum,

10 bone, lymphatic system, skin, or in any other organ or tissue of the subject.

The inventive methods are useful in treating any mammal, including a human, non-human primate, canine, feline, bovine, porcine or ovine mammal, as well as in a small mammal such as a mouse, rat, gerbil, hamster, or rabbit.

The potassium channel agonist is an activator of either a calcium-activated potassium

15 channel (K_{Ca}) of any conductance level, whether of large, intermediate, or small conductance, or of an ATP-sensitive potassium channel (K_{ATP}). Examples of useful potassium channel agonists that are K_{Ca} activators include 1,3-dihydro-1-[2-hydroxy-5-(trifluoromethyl)phenyl]-5-(trifluoromethyl)-2H-benzimidazol-2-one (NS-1619) or 1-ethyl-2-benzimidazolinone (1-EBIO). Other examples include soluble guanylyl cyclase activators, such as, metalloporphyrins (e.g.,

20 zinc or tin protoporphyrin IX), YC-1 (a benzyl indazole derivative), or guanylyl cyclase activating proteins (GCAPs).

Examples of useful potassium channel agonists that are K_{ATP} activators include minoxidil (2,4-diamino-6-piperidino pyramidine-3-oxide; insoluble in water, soluble in ethanol 29 mg/mL), pinacidil ((+/-)-N-cyano-N'-4-pyridinyl-N''-(1,2,2-trimethyl propyl)-guanidine; insoluble in

25 water, soluble in ethanol 14 mg/mL]), (+)-cromakalim, (-)-cromakalim or levcromakalim, (+/-)-cromakalim, or diazoxide. Included among useful potassium channel agonists are pharmaceutically acceptable molecular conjugates or salt forms that still have activity as potassium channel agonists. An example is minoxidil sulfate, but other pharmaceutically acceptable salts comprise anions other than sulfate, such as carbonate, bicarbonate, nitrate, or the

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like. Other embodiments of pharmaceutically acceptable salts contain cations, such as sodium, potassium, magnesium, calcium, or the like. Other embodiments of useful potassium channel agonists are hydrochloride salts.

However, the potassium channel agonist employed in the inventive methods is one other

5   than the vasodilator bradykinin (Arg-Pro-Pro-Gly-Phe-Ser-Pro-Phe-Arg), or a polypeptide bradykinin analog, such as receptor mediated permeabilizer (RMP)-7 or A7 (e.g., Kozarich *et al.*, U.S. Patent No. 5,268,164 and PCT Application No. WO 92/18529). Other analogs of bradykinin include related peptide structures which exhibit the same properties as bradykinin but have modified amino acids or peptide extensions on either terminal end of the peptide.

10 Examples of bradykinin analogs include [phe.sup.8 (CH.sub.2 –NH) Arg.sup.9]-bradykinin, N–acetyl [phe.sup.8 (CH.sub.2 --NH--Arg.sup.9] bradykinin and desArg9-bradykinin.

In accordance with the inventive methods, the potassium channel agonist is administered by intravenous or intra-arterial injection or infusion. For treating an abnormal brain region, such as an intracranial tumor, the potassium channel agonist is preferably administered by intracarotid

15 infusion. The amount of potassium channel agonist to be administered ranges from 0.075 to 1500 micrograms per kilogram body mass. For humans the range of 0.075 to 150 micrograms per kilogram body mass is most preferred. This can be administered in a bolus injection, but is preferably administered by infusion over a period of one to thirty minutes, and most preferably during a period of one to fifteen minutes. For example, in rats, a dose rate of about 0.75 to about

20 100 $\mu g \, kg^{-1} \, min^{-1}$ is most suitable. At dose rates above about 100 $\mu g \, kg^{-1} \, min^{-1}$ a concomitant fall in blood pressure has been observed   In humans, effective dose rates are about 0.075 to about 15 $\mu g \, kg^{-1} \, min^{-1}$, with cautious monitoring of blood pressure being advised. The practitioner skilled in the art is also cautious in regulating the total infusion volume, rate of liquid infusion, and electrolyte balance to avoid adverse physiological effects related to these.

25 Some potassium channel agonists, such as NS-1619, minoxidil, minoxidil sulfate, pinacidil, or diazoxide are not easily dissolved in water; in preparing these agents for administration, a suitable and pharmaceutically acceptable solvent, such as ethanol, can be used to dissolve the potassium channel agonist prior to further dilution with an infusion buffer. The skilled practitioner is cautious in regulating the final concentration of solvent in the infusion

solution to avoid solvent-related toxicity. For example, a final ethanol concentration in an infusion solution up to 5-10% (v/v) is tolerated by most mammalian subjects with negligible toxicity.

5   While the inventive method does not depend on any particular mechanism by which increased microvascular permeability to the medicant is achieved, it is thought that administration of the potassium channel agonist increases potassium flux through potassium channels in endothelial cell membranes of the capillaries and arterioles delivering blood to abnormal brain regions and/or malignant tumors. This results in a loosening of tight junctions in the microvascular epithelium and/or increased pinocytotic activity, enhancing the uptake of

10   medicants from the blood vessels. In practicing the inventive methods, it is not necessary to measure potassium channel activity (i.e., potassium cation flux therethrough). But the skilled artisan is aware that potassium flux can be measured by any suitable method, for example, by measuring cellular uptake of $^{42}K^+$ or $^{201}Tl^+$ or channel conductance using patch-clamp or microelectrode devices. (e.g., T. Brismar *et al.*, *Thallium-201 uptake relates to membrane*

15   *potential and potassium permeability in human glioma cells*, Brain Res. 500(1-2):30-36 [1989]; T. Brismar *et al.*, *Mechanism of high K^+ and Tl^+ uptake in cultured human glioma cells*, Cell Mol. Neurobiol. 15(3):351-60 [1995]; S. Cai *et al.*, *Single-channel characterization of the pharmacological properties of the K(Ca2+) channel of intermediate conductance in bovine aortic endothelial cells*, J. Membr. Biol. 163(2):147-58 [1998]).

20   The medicant is administered simultaneously or substantially simultaneously with the potassium channel agonist, and the medicant is delivered by the blood stream selectively to the abnormal brain region and/or to the malignant cells compared to normal brain tissue or non-malignant cells. "Simultaneously" means that the medicant is administered contemporaneously or concurrently with the potassium channel agonist. "Substantially simultaneously" means that

25   the medicant is administered within about one hour after the potassium channel agonist is last administered, preferably within about 30 minutes after, and most preferably, is administered simultaneously with the potassium channel agonist. Alternatively, "substantially simultaneously" means that the medicant is administered within about 30 minutes before, and preferably within about 15 minutes before the potassium channel agonist is first administered.

The methods of delivering a medicant to an abnormal brain region and/or to a malignant tumor in a mammalian subject are effective in selectively delivering any medicant across the microvascular of an abnormal brain region and/or malignant tumor. The medicant is a drug, i.e., a chemotherapeutic agent. Example of chemotherapeutic agents including therapeutic cytotoxic

5   agents (e.g., cisplatin, carboplatin, methotrexate, 5-fluorouracil, amphotericin), "naked" DNA expression vectors, therapeutic proteins, therapeutic oligonucleotides or nucleotide analogs, interferons, cytokines, or cytokine agonists or antagonists, adrenergic agents, anticonvulsants, anti-trauma agents, or any neuropharmaceutical agent used to treat or prevent an injury or disorder of the brain. Chemotherapeutic agents also include ischemia-protective drugs such as

10   N-methyl-D-aspartate (NMDA) receptor antagonists; antimicrobial agents, such as antibiotics; immunotoxins, immunosuppressants, boron compounds, monoclonal antibodies and specific antigen-binding antibody fragments (e.g., Fab, Fab', F(ab')$_2$, or F(v) fragments), and cytokines, such as interferons, interleukins (e.g., interleukin [IL]-2), tumor necrosis factor (TNF)-α, or transforming growth factors (e.g., TGF-β).

15   The medicant also includes anticancer chemotherapeutic agents. Typically, anticancer chemotherapeutic agents are cytotoxic agents, such as 5-fluorouracil, cisplatin, carboplatin, methotrexate, daunorubicin, doxorubicin, vincristine, vinblastine, or a cytotoxic alkylating agent, such as, but not limited to, busulfan (1,4-butanediol dimethanesulphonate; Myleran, Glaxo Wellcome), chlorambucil, cyclophosphamide, melphalan, or ethyl ethanesulfonic acid. The

20   anticancer chemotherapeutic agents are particularly useful in practicing the method of selectively delivering a medicant to a malignant tumor, in the brain or in any other tissue of the body, and in the method of treating a malignant tumor in a human subject.

Medicants also include any therapeutic viral particle, for example an adenovirus-derived or herpes simplex virus (HSV)-derived viral vector for delivering genetic material to a cellular

25   target in vivo. Medicants also include diagnostic agents, such as imaging or contrast agents, for example, radioactively labeled substances (e.g., [^{99}Tc]-glucoheptonate), gallium-labeled imaging agents (e.g., gallium-EDTA), ferrous magnetic, fluorescent, luminescent, or iodinated contrast agents. Where suitable, any of the afore-mentioned medicants having anticancer

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activity can also be used in practicing the method of selectively delivering a medicant to a malignant tumor or the method of treating a malignant tumor in a human subject.

Thus, the medicant can be a molecular substance having a molecular weight between about 50 D and about 250 kD. Or it can be a particle, such a s a viral particle, having a diameter

5   between about 50 to 250 nanometers.

This is by no means intended to be an exhaustive list of the kinds of medicants that can be employed in practicing the inventive methods. The medicant can be, but is preferably not, an agent that is highly lipid soluble and thus inherently able to penetrate cell membranes, for example nitrosourea.

10   The amount of medicant that is employed is within a conventional dose range for each medicant, however by practicing the inventive method, the increased transvascular permeability afforded can provide a greater selective therapeutic effect per dose or permit a lower effective dose to be used, if desired, for example to lessen systemic toxic effects from anti-cancer medication in a particular subject.

15   The medicant is administered by any appropriate method that can deliver it to the blood stream. Typically, this is by intravenous, intramuscular, or intra-arterial (including intracarotid) injection or infusion. However, for some applications other acceptable delivery routes can be used as long as the dose of medicant enters the blood stream substantially simultaneously with the potassium channel agonist. Examples include ingestion (e.g., of a powder, suspension,

20   solution, emulsion, tablet, capsule or caplet); subcutaneous injection; stereotactic injection; or transdermal or transmucosal delivery by adhesive patch, suppository or gel for delivery through the skin, mucosa or epithelium of the mouth including the sublingual epithelium, the rectum, or the vaginal epithelium.

Alternatively, the medicant is administered together with the potassium channel agonist

25   in a pharmaceutical composition of the present invention. The inventive pharmaceutical composition comprises a combination of a potassium channel agonist, other than bradykinin or a bradykinin analog, as described above, formulated in a pharmaceutically acceptable solution together with a medicant, as described above, for delivery by intravascular infusion or bolus injection into a mammal, such as a human. The solution is thus suitably balanced, osmotically

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(e.g., about 0.15 M saline) and with respect to pH, typically between pH 7.2 and 7.5; preferably the solution further comprises a buffer, such as a phosphate buffer (e.g., in a phosphate buffered saline solution). The solution is formulated to deliver a dose rate of about 0.075 to 1500 micrograms of potassium channel agonist per kilogram body mass in a pharmaceutically

5   acceptable fluid volume over a maximum of about thirty minutes. For human subjects, the solution is preferably formulated to deliver a dose rate of about 0.075 to 150 micrograms of potassium channel agonist per kilogram body mass in a pharmaceutically acceptable fluid volume over a period of up to about thirty minutes.

The invention also relates to a kit for enhancing the delivery of a medicant to an abnormal

10   brain region and/or to a malignant tumor. The kit is an assemblage of materials or components, including a potassium channel agonist, other than bradykinin or a bradykinin analog, as described above. In addition, the kit contains instructions for using the potassium channel agonist to enhance the permeability of abnormal microvascular, including neomicrovasculature, to a medicant in general, or alternatively, to a particular medicant. Optionally, the kit also contains

15   other components, such as a particular medicant in any pharmaceutically acceptable formulation, or paraphernalia for injection or infusion, for example syringes, infusion lines, clamps, and/or infusion bags/bottles, which can contain a pharmaceutically acceptable infusible formulation of the potassium channel agonist with or without a particular medicant also contained therein. The materials or components assembled in the kit can be provided to the practitioner stored in any

20   convenient and suitable ways that preserve their operability and utility. For example the components can be in dissolved, dehydrated, or lyophilized form; they can be provided at room, refrigerated or frozen temperatures.

The foregoing descriptions of the methods and kits of the present invention are illustrative and by no means exhaustive. The invention will now be described in greater detail

25   by reference to the following non-limiting examples.

EXAMPLES

Example 1: Methods

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Malignant Cell Line and Tumor Implantation. A rat glioma cell line, RG2, was used for implantation of experimental brain tumors in Wistar rats. The techniques for RG2 cell propagation and maintenance in tissue culture have been described (Sugita, M. and Black, K.L., *Cyclic GMP-specific phosphodiesterase inhibition and intracarotid bradykinin infusion enhances permeability into brain tumors*, Cancer Res. 58(5):914-20 [1998]; Inamura *et al.* [1994]; Nakano, S. *et al.*, *Increased brain tumor microvessel permeability after intracarotid bradykinin infusion is mediated by nitric oxide*, Cancer Res. 56(17):4027-31 [1996]). Briefly, RG2 cells derived from a rat glioma are kept frozen until use, then are thawed and maintained in a monolayer culture in F12 medium with 10% calf serum.

The Wistar rats (approximately 140-160 g body weight) were anesthetized with intra-peritoneal ketamine (50 mg/kg), and glial cells (1 x 10^5) were implanted into the right hemisphere, but not the contralateral hemisphere, by intracerebral injection suspended in 5 μL F12 medium (1-2% methylcellulose) by a Hamilton syringe. The implantation coordinates were 3-mm lateral to the bregma and 4.5 mm deep to the dural surface.

Intracarotid Infusion of Potassium Channel Activators. Seven days after implantation of RG2 cells, the rats were anesthetized as described above and prepared for permeability studies. Animals were infused with either NS-1619 (a selective large conductance Ca^{2+}- activated K^+ channel activator; RBI, Natick, MA) or minoxidil sulfate (a K_{ATP} channel activator) into the right carotid artery at a dose rate of 7.5 μg kg^{-1} min^{-1} (in 53.3 μL/min) for 15 minutes, in an infusion vehicle of PBS, pH 7.4; 5% (v/v) ethanol. Ethanol (25% [v/v]) was used to dissolve the potassium channel agonists before dilution in PBS. For blood volume studies, 5 and 14 minutes after the start of the intracarotid infusion of potassium channel agonist compounds, [^{14}C] Dextran (100 μCi/kg; Dupont-New England Nuclear Co., Boston, MA) was injected as an intravenous bolus and maintained for 1 minute and 10 minutes to obtain two different time points. For regional permeability studies, 5 minutes after the start of the intracarotid infusion of vasoactive compounds, 100 μCi/kg of [^{14}C]α-aminoisobutyric acid (Dupont-New England Nuclear Co., Boston, MA) was injected as an intravenous bolus. A peristaltic withdrawal pump was used to withdraw femoral arterial blood at a constant rate of 0.083 mL/min immediately after the

injection of the tracer to determine serum radioactivity. Fifteen minutes after the intracarotid infusion, rat decapitated and the brain rapidly removed and frozen for quantitative autoradiography.

Unidirectional Transport Constant (K_i). The unidirectional transfer constant K_i for [^{14}C]α-

5 aminoisobutyric acid was measured in normal tissue and tumor tissue as an indicator of permeability across the blood-tumor and blood-brain barriers. Quantitative autoradiography was used to obtain K_i values (μL g^{-1}min^{-1}). The initial rate for blood-to-brain transfer was calculated using a previously described equation. (Ohno, K, *et al.*, *Lower limits of cerebrovascular permeability to nonelectrolytes in the conscious rat*, Am. J. Physiol. 235(3):H299-307, [1978];

10 Inamura, T., *et al.*, *Bradykinin selectively opens blood-tumor barrier in experimental brain tumors*, J. Cereb. Flow Metab. 14(5):862-70 [1994]). Quantitative data were analyzed using, two group t-test and two-group Fisher's-exact test of equal proportions or equal means (equal numbers) at 90% power requires a minimum of 6 animals in each group to achieve statistical significance. Multiple treatment groups were compared with control group by ANOVA and P

15 values determined by post-hoc Bonferroni test.

Dose-dependence studies. NS-1619 was dissolved in 25% ethanol and diluted with PBS to obtain various concentrations for infusion. NS-1619 was administered by intracarotid infusion (dose rates: 0, 13, 26.5, 53, 80, 100 and 110 μg kg^{-1} min^{-1}; all at 53.3 μL/min) to RG2 glioma-bearing rats to determine a dose that produces increased permeability (K_i) of [^{14}C]-AIB, which

20 was administered intravenously. K_i determined as described above. Physiological parameters were monitored during the experiments.

Inhibition studies. Since NS-16129 increased permeability, the specificity of its effect was examined using the specific K_{Ca} channel inhibitor, iberiotoxin (RBI, Natick, MA). Iberiotoxin (IBTX) was diluted in saline to a final concentration of 100 μg/mL. IBTX (2.3 μg kg^{-1} min^{-1})

25 was co-infused with NS-1619 (26.5 μg kg^{-1} min^{-1}) to block K_{Ca} channel-induced permeability in abnormal capillaries in the RG2 glioma model. Seventeen rats were used for these studies (3

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vehicle-only control [i.e., PBS ± 5% (v/v) ethanol]; 3 IBTX; 8 NS-1619; 3 NS-1619 + IBTX).

K_i for [^{14}C]-AIB was determined by quantitative autoradiography as described earlier by Ohno *et al.* (1978).

Immunohistochemical analysis for K_{Ca} channels.   Brain sections (12 μm thick) obtained from

5   the permeability studies were incubated with 1:100 dilution of affinity-purified K_{Ca} channel

antibody (Alomone Labs, Jerusalem, Israel) for 1 hour, and biotinylated horse anti-mouse

immunoglobin (Vector Laboratories, Burlingame, CA) for 30 minutes. After washing 3 times

with PBS, the peroxidase sites were visualized using an avidin:biotinylated enzyme complex

(ABC) kit.

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Example 2: Results

Potassium Channel Activators Selectively Increase Transport Across the Blood-tumor Barrier.

When Wistar rats bearing implanted glioma cells were infused with either NS-1619 or

minoxidil sulfate, at 7.5 μg kg^{-1} min^{-1} for 15 minutes, the unidirectional transport constant K_i for

15   [^{14}C]α-aminoisobutyric acid (AIB) was significantly increased by both NS-1619 and minoxidil

sulfate with respect to transport across the neovasculature forming the blood-tumor barrier, but

not with respect to transport across normal brain microvasculature. (Figures 1A and 1B). These

results demonstrate that activation of potassium calcium channels selectively increases the

permeability of molecules across the capillaries of solid malignant tumors compared to

20   capillaries supplying normal brain tissue.

The dose-dependent nature of this increased permeability is demonstrated in Figure 2,

which shows that increasing the dose of NS-1619 results in an increase in the unidirectional

transfer constant K_i for [^{14}C]α-aminoisobutyric acid in RG2 glioma capillaries. At higher doses

(100 and 110 μg/kg/min) a significant drop in the arterial blood pressure of the rats was

25   observed. The numbers of rats used in each group is shown in parentheses in Figures 2.

The specificity of this effect is demonstrated in Figure 3, which shows that the ability of

NS-1619 to increase the unidirectional transfer constant K_i for [^{14}C]α-aminoisobutyric acid was

inhibited by the K_{Ca}-channel-specific inhibitor iberiotoxin (IBTX). The K_i was determined in RG2 tumor-bearing rats using $[^{14}C]$ AIB with NS-1619 (26.5 µg min^{-1} kg^{-1}) with or without IBTX (2.3 µg kg^{-1} min^{-1}; n=3), for 15 minutes. Increase of K_i in response to NS-1619 infusion (n=8; ** $P<0.001$ compared with PBS with or without 5% ethanol) was attenuated by IBTX co-

5 treatment. IBTX alone at the dose investigated did not affect the brain-tumor barrier permeability of abnormal capillaries. However, IBTX significantly (n=3, ** $P<0.001$ compared with NS-1619-treated group) decreased NS-1619-induced increase of permeability (K_i), indicating a potassium channel-specific effect.   Controls receiving PBS plus 5% ethanol were indistinguishable from controls receiving PBS minus ethanol.

10 Immunohistochemical Analysis Shows Potassium Channels Are More Abundant in Neovasculature and Malignant Cells Compared to Normal Tissue.

K_{Ca} channel protein was immunolocalized using a specific antibody as described above. Immunohistochemical analysis showed that K_{Ca} channels were selectively increased in tumor tissue and tumor capillaries in RG2 bearing rat brain sections, compared to sections of normal

15 contralateral tissue. (Figure 4). These immunohistochemical results are consistent with the permeability data in which activation of K_{Ca} channel by NS-1619 selectively opened the blood-tumor barrier. (Figure 1A).

Together, the permeability and immunohistochemical data demonstrate that compounds that activate potassium channels can be used to selectively increase delivery of anti-tumor

20 compounds to malignant tumor tissue.

The foregoing examples being illustrative but not an exhaustive description of the embodiments of the present invention, the following claims are presented.